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SULFUR OXIDE THROWAWAY SLUDGE EVALUATION PANEL (SOTSEP). VOLUME I: EXECUTIVE SUMMARY

Frank T. Princiotta

National Environmental Research Center
Research Triangle Park, North Carolina

April 1975

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SULFUR OXIDE THROWAWAY SLUDGE EVALUATION PANEL (SOTSEP), VOLUME I: FINAL REPORT - EXECUTIVE SUMMARY

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The report gives results of an intermedia evaluation of the environmental and economic factors associated with disposal or utilization of sludge from non-regenerable flue gas desulfurization processes. The evaluation was conducted in the context of alternate sulfur oxide control techniques; existing and anticipated air, solid waste, and water standards; and other major influences on the potential generation of sludge, its disposal, and the magnitude of potential environmental problems associated with its disposal. This volume gives a concise review of the findings and technical recommendations, as well as details of each specific study category.

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FOREWORD

This report by EPA's Sulfur Oxide Throwaway Sludge Evaluation Panel (SOTSEP) presents the results of an intermedia evaluation of the environmental and economic factors associated with disposal or utilization of sludge from nonregenerable flue gas desulfurization processes. The evaluation was conducted in the context of alternate sulfur oxide control techniques; existing and anticipated air, solid waste, and water standards; and other factors which might have a major influence on the potential generation of sludge, its disposal, and the magnitude of any potential environmental problems associated with its disposal.

The SOTSEP consisted of the following EPA members who participated in panel activities and co-authored the report:

Frank Princiotta (Chairman) - Office of Research and Development (ORD), National Environmental Research Center-Research Triangle Park (NERC-RTP), Control Systems Laboratory (CSL), Gas Cleaning and Metallurgical Processes Branch (GCMPB)

Arnold Goldberg - ORD, Air Pollution Control Division (APCD)

Julian Jones - ORD, NERC-RTP, CSL, GCMPB

William Schofield - ORD, NERC-RTP, CSL, Engineering Analysis Branch (EAB)

Richard Stern - ORD, NERC-RTP, CSL, GCMPB

Robert Walsh - Office of Air and Waste Management (OAWM), Emission Standards and Engineering Division (ESED), Office of Control Technology (OCT)

In addition to the above air pollution technology oriented members, the panel included water and solid waste pollution technology oriented associate members who actively participated in a consulting role and supplied inputs for the report:

Alden Christianson - ORD, NERC-Corvallis, Thermal Pollution Research Programs (TPRP)

Robert Dean - ORD, NERC-Cincinnati, Advanced Waste Treatment Research Laboratory (AWTRL), Ultimate Disposal Research Program (UDRP)

Ronald Hill - ORD, NERC-Cincinnati, AWTRL, Mine Drainage Pollution Control Activities (MDPCA)

Jack Keeley - ORD, NERC-Corvallis, Robert S. Kerr Environmental Research Laboratory, Ground Water Research (GWR)

Norbert Schomaker - ORD, NERC-Cincinnati, Solid and Hazardous Waste Research Laboratory (SHWRL), Disposal Technology Branch (DTB)

The results of the SOTSEP activity are presented in two separate volumes each covering the following general categories:

Definition of the problem - status of alternative sulfur oxide control technology, potential demand for lime/limestone scrubbing, quantification of the problem and comparison with analogous environmental problems, impact of SO_x scrubber sludge relative to current and proposed regulation/enforcement, and nature of the material.

Approaches to disposing of or utilizing scrubber sludge materials - commercial utilization, current and planned industry disposal, disposal by ponding, disposal by landfill, other disposal, and current EPA R&D programs.

Alternative sulfur by-products - technologies for production, economic and marketing considerations for elemental sulfur, sulfuric acid, gypsum, sodium sulfate, ammonium sulfate, and liquid SO_2, environmental considerations, and economic and environmental comparison with scrubber sludge.

Volume I, the Executive Summary, presents the panel findings and technical recommendations, followed by a Technical Discussion Summary which provides further details in each specific category of study.

Volume II, the Technical Discussion, provides a comprehensive discussion of each specific area of study and supplies

back-up information and references for the Volume I Technical Discussion Summary.

Because of time constraints, SOTSEP activities were streamlined by working in accordance with the following groundrules:

1. The scope of the activities focused primarily on SO_x and particulate control for coal-burning power plant emissions. The flue gas desulfurization process was assumed to operate in a closed-loop with no direct discharge; liquor leaves the system only by evaporative losses in the scrubber and by inclusion with the sludge.

2. The study assumed that there would be no major deviations from either the Clean Air Amendments of 1970 or EPA's present implementation policies, through 1980.

3. Readily available information was utilized to the maximum possible extent.

4. Current CSL contractors were utilized to the maximum possible extent.

ACKNOWLEDGEMENTS

Appreciation is acknowledged for the timely and responsive assistance of the following:

Radian Corporation which accumulated and evaluated a major portion of information, provided an early draft version of the Technical Discussion, and assisted in preparation of the final version of the report.

Aerospace Corporation which supplied scrubber sludge utilization information and chemical and physical property data, and assisted in review of the Executive Summary.

CSL secretaries Carolyn Fowler, Charlotte Bercegeay, Virginia Purefoy, Linda DeVinney, Gloria Rigsbee, Lynn Pendergraft, and Theresa Butts.

METRIC CONVERSION FACTORS

In compliance with EPA policy, metric units have been used extensively in this report (followed by British units in parentheses). However, in some cases, British units have been used for ease of comprehension. For these cases, the following conversion table is provided:

British	Metric
1 Btu	252 calories
1 Btu	2.93×10^{-4} kilowatt-hours
5/9 (^{o}F-32)	^{o}C
1 ft	0.3048 meter
1 ft^2	0.0929 meters^2
1 ft^3	0.0283 meters^3
1 yd	0.9144 meters
1 yd^2	0.8361 meters^2
1 yd^3	0.7646 meters^3
1 mile	1.609 kilometers
1 mile^2	2.59 kilometers^2
1 acre	4047 meters^2
1 pound	0.4536 kilograms
1 ton (short)	0.9072 metric tons

FINDINGS

Assessment of the available information by SOTSEP members and associate members has resulted in the following general finding:

> Lime/limestone scrubbing, with controlled disposal of scrubber sludge* is an environmentally acceptable approach to near-term flue gas pollutant control. Although the total environmental impact associated with disposal of untreated sludge in a soil-lined disposal area is not completely defined, currently available technology appears to be capable of environmentally acceptable disposal. A high degree of confidence in eliminating potential secondary pollution effects can be achieved with a combined approach incorporating pond lining and chemical treatment (fixation). On the other hand, health effects data on air pollutants (notably sulfur compounds) sufficiently indicate the hazards of their emission. Consequently, prevention of these emissions with subsequent containment of air pollutants and controlled disposal is clearly preferred over uncontrolled emission into the atmosphere.

The specific findings which follow are related to each of the three major study categories. Additional specific

*Regenerable flue gas desulfurization processes (i.e., those producing sulfuric acid or elemental sulfur) do not produce sludge as a waste product.

findings are included in a fourth category which summarizes the key findings relevant to technical recommendations.

I. DEFINITION OF THE PROBLEM

1. Based on a review of SO_x control technologies, installation of flue gas desulfurization (FGD) systems on units burning high-sulfur coal is the major alternative to scarce clean fuels which can be commercially available between now and 1980. Other technological alternatives such as coal gasification, coal liquefaction, and advanced combustion processes are not expected to make a significant contribution to clean fuel availability until after 1980. Based on current trends, technology availability, qualified system suppliers, and lead time considerations, the majority of FGD system installations through 1980 will be lime/limestone wet scrubbing processes.

2. Installation of FGD systems is presently demand-limited; regulatory pressures are expected to change this to a supply-limited situation sometime between 1975 and 1977 which will continue through about 1980. Under these conditions, it is estimated that FGD control will most likely be installed on 90,000 Mw or about 35% of total estimated coal-fired utility generating capacity by 1980. High-sulfur oil-fired utility plants, high-sulfur coal-fired industrial boilers, and other sources such as smelters and acid plants are not included. Most of the 90,000 Mw capacity is expected to be controlled by lime/limestone wet scrubbing systems producing a throwaway sludge. Assuming all of the installations to be lime/limestone systems* 119,000,000 metric tons/year (131,000,000 tons/year)

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*It is unlikely that all the coal-fired utility FGD installations will be lime/limestone systems. However, the majority are expected to be, and other applications (e.g., oil-fired utility boilers, coal-fired industrial boilers) could make the projected production figure quite realistic.

of wet* limestone sludge including ash, or 108,000,000 metric tons (119,000,000 tons) of wet lime sludge including ash, will be produced in 1980. If projected viability and availability of alternative clean-fuel technologies does not materialize, annual sludge production could be substantially higher in the post-1980 period.

3. Several types of dry solid and sludge wastes other than those produced by FGD processes, many of which contain potentially hazardous constituents, have been generated in great quantities and disposed of by ponding or landfill for many years. Although some of the problems associated with disposal of non-FGD wastes are not completely resolved, techniques have been developed which provide varying degrees of environmental protection.

4. To place scrubber sludge in quantitative perspective, three comparisons are presented:

a. Approximate rates of solid waste production for a typical 1000 Mw coal-fired power plant:

Waste	Production Rate, 10^3 Short Tons/Year	
	Dry Basis	Wet Basis
Deep Mining Wastes (Coal)	94.2	97.1 (97% solids) (in addition, 4.205×10^3 tons of acid mine drainage sludge)
Surface Mining Wastes (Coal)	2707	2762 (98% solids) (in addition, 0.328×10^3 tons of acid mine drainage sludge)
Processing Wastes	450	454 (99% solids)
Scrubber Sludge (exclusive of ash)[a]	392	784 (50% solids)
Coal Ash[a]	338	a. 423 (80% solids) (ash collected in different pond than scrubber sludge)
		b. 676 (50% solids) (fly ash collected in scrubber and sluiced to same pond as bottom ash)
Total Wastes, Deep Mining Case	1274	2011[b]
Total Wastes, Surface Mining Case	3887	4676[b]

[a] For 3.0% S, 12% ash, 6400 hrs/yr, limestone scrubbing, 85% SO_2 removal, 100% ash removal, $CaCO_3$ to SO_2 mole ratio is 1.20.

[b] For coal ash collection method b.

*Unless otherwise specified, sludge tonnage is on a wet (50% solids) basis including ash.

b. Associated land usage for a typical 1000 Mw coal-fired power plant:

Item	Distribution of Land Usage with Limestone FGD for SO_2 and Particulate, Ponded Untreated Sludge	Distribution of Land Usage with Particulate Control Only, Ponded Ash
Surface Mining	40.9%	41.2%
Processing	0.5	0.5
Rail Transport	6.5	6.4
Plant Site	1.0	1.0
Plant Site Waste (combustion and pollution control)	1.1 (sludge incl. ash)	0.3 (ash only)
Transmission Lines	50.0	50.6
	100.0% (Total of 34,289 acres)	100.0% (Total of 34,021 acres)

It may be seen that land usage related to plant site wastes is a small fraction of total land usage. However, it should be noted that the environmental impact of each individual usage varies considerably, requiring consideration of many factors other than the relative areas involved.

c. Comparison with other sources of solid waste:

The comparison of projected levels of scrubber sludge with the quantities of solid waste generated by other industries provides a means of placing sludge disposal into proper perspective. The following table summarizes the quantities of waste material produced by several typical industries and compares existing and projected levels of waste requiring disposal with 1980 projections of scrubber sludge. All figures are on an "as disposed" basis.

Waste Material	Wt % Solids	"As Disposed" Quantity, 10^6 Metric Tons/Year	(Reference Year)
Mineral Ore Wastes	100	1300	(1970)
Taconite Tailings	4-5	1100	(1971)
Phosphate Rock Slime	4-6	760	(1970)
Municipal and Industrial Refuse	75	360	(1973)
Coal Ash	80	95	(1980)
Culm Piles	100	>91	(1969)
Limestone Scrubber Sludge	50	64	(1980)
Municipal Sewage Sludge	0.1-20	55	(1980)
Gypsum from Fertilizer Manufacturer	85-90	28	(1973)
Acid Mine Drainage Sludge	1-5	8.2	(1973)

5. To place scrubber sludge in <u>qualitative</u> perspective, the following comparison with coal ash is presented:

a. Although the detailed composition of sludges will vary somewhat from system to system, the major constituents are generally calcium sulfite ($CaSO_3 \cdot \frac{1}{2}H_2O$), calcium sulfate ($CaSO_4 \cdot 2H_2O$), calcium carbonate ($CaCO_3$), and unreacted lime ($CaO$). Depending on the physical layout of the total emissions control system, more or less fly ash is associated with the sludge. The major constituents in fly ash are silica (SiO_2), alumina (Al_2O_3), and ferric oxide (Fe_2O_3) in discrete and mixed compounds. The calcium compounds have a limited solubility in sludge liquors. The major components in fly ash are even less soluble.

b. Sludge solids will also contain trace elements and other species originating in the coal, limestone or

lime, and make-up water. The primary source of trace elements is the coal. Ash solids will also contain trace elements and other species originating in the coal and ash sluice water.

c. Sludge and ash liquors will contain dissolved solids up to the solubility limits of individual species. The solubilities are highly pH dependent with the general trend of increasing solubility with increasing acidity (low pH). The pH of the liquors is a function of the chemistry of the coal and the mode of scrubber operation. For example, use of an excess of lime or limestone can increase the pH, reducing the solubility of most components.

d. Even in the absence of appreciable quantities of fly ash, sludge liquors may contain species, such as chlorides and certain trace metals, which can be volatilized during coal or oil combustion and removed in the scrubber. These species are generally not collected by dry ash collection techniques so they are emitted to the atmosphere and consequently not found in the ash liquor. (This indicates the potential multipollutant control capability of wet scrubbing.)

e. Data indicate that untreated scrubber sludge settles to 30-65% solids. At this concentration, sludge would require more storage volume per unit weight than coal ash, which settles to about 80% solids. Technologies such as oxidation are being developed to increase the solids content, thereby decreasing the volume required for storage.

6. The enacted Federal Water Pollution Control Amendments of 1972 and the proposed solid waste management acts require EPA to issue and periodically update guidelines and limitations regarding water discharge and waste disposal

practices. In the Federal Water Pollution Control Act Amendments of 1972, Congress stated that the national goal was to eliminate the discharge of pollutants into all waters. Pending legislation, the Safe Drinking Water Act of 1974 strongly addresses the need for protection of groundwater supplies. It is apparent that the approach Congress is taking is the elimination or minimization of discharges into surface waters and groundwaters. Typically, lime/limestone systems are designed to operate in a closed-loop mode, which means that there is no direct discharge of liquor from the system. A certain amount of liquor is contained in the system's waste sludge; however, proper disposal methods can prevent leaching of this liquor to the natural water system. Therefore, technology is available for compliance with the restrictions set forth by this legislation. Additional research and development is planned and underway to insure the uniform applicability of the best available technology to the variety of FGD systems installed or contemplated.

II. APPROACHES TO DISPOSING OF OR UTILIZING SCRUBBER SLUDGE MATERIALS

1. Appreciable commercial utilization of sulfur oxide sludge is unlikely. Disposal by ponding and landfill appears to be the only important near-term alternative.

2. Based on 15 current lime/limestone FGD system installations, utilities are presently favoring ponding over landfill disposal techniques by about a 3:2 ratio.

3. Technologically, a high degree of confidence may be achieved with an approach incorporating pond lining in combination with chemical treatment (fixation). It appears, however, that this conservative approach may not be necessary but that proper ponding or fixation alone may be environmentally sound.

4. For ponding, available information indicates that water pollution problems can be prevented by proper pond engineering, installation of a pond liner, and by operating in a closed-loop mode. Installed costs for synthetic pond liners for a 0.4 to 4.0 hectare pond (1 to 10 acres) range from approximately $1.20 per square meter ($1.00 per square yard) for thin synthetic membranes up to $7.90 per square meter ($6.60 per square yard) for 30 mil fabric reinforced rubber. Clay lining starts at $1.80 per square meter ($1.50 per square yard) and may go up to $10.80 per square meter ($9.00 per square yard) or higher depending on the hauling distance. These cost figures do not include pond excavation costs. Based on the assumptions given in Case 5, Table 2 (in Technical Discussion Summary), $1.20 per square meter ($1.00 per square yard) is equivalent to about $4/Kw capital cost. A general cost range for a total ponding operation, exclusive of future reclamation costs, is $2.50-4.50 per ton of wet sludge (50% solids). Based on the same assumptions referred to above, this range is equivalent to 0.6-1.0 mills/Kwh. Specifications for lining materials for sludge disposal applications and, consequently, their cost effectiveness are not well defined. Because of nonsettling characteristics of sludges, ponding may not be an acceptable disposal method in many areas because it may result in land deterioration and be a temporary solution only. On the other hand, ponding does enable the operator to postpone determination of final disposal for several years. Documented cases of technology and costs for effective reclamation of sludge ponds are

not available. However, available data on sludge chemical fixation (see II(5)) indicate that this technology can eliminate land deterioration problems.

5. For landfilling, available information indicates that chemical treatment (fixation) of sludge will eliminate land deterioration problems in cases where the load-bearing characteristics of untreated sludge are inadequate. Fixation may also avoid water pollution problems in unlined landfill sites, but further study is needed to evaluate the degree of leaching and the degree of attenuation offered by different substrates for individual sludges. Fixation processes are being commercially offered and in some cases vendors have active contracts with utilities to handle lime/limestone sludge. Because of proprietary considerations, vendors and utilities generally have not released details of their sludge disposal processes; therefore, it is difficult to completely assess their cost. However, available small-scale test data have indicated lower permeability and leachability, as well as improved compressive strength and other material properties. Operating costs reported by utilities performing their own disposal range from $5.25-10/wet ton for on-site disposal; this is exclusive of capital costs. Vendors' estimates are much lower, ranging from $2-6/wet ton as a total disposal cost. These costs are affected by many variables, including sludge characteristics and chemistry, transport distances, and land values, resulting in the wide range for the estimates. Typical cases are expected to be in the range of $2.50-5.00/wet ton. Based on the assumptions given in Case 5, Table 2 (in Technical Discussion Summary), fixation at $2.50-5.00/wet ton (including ash) is equivalent to approximately 0.6-1.1 mills/Kwh.

III. ALTERNATIVE SULFUR BY-PRODUCTS

1. Economic comparisons of lime/limestone FGD with regenerable FGD systems are strongly influenced by sludge disposal costs which in turn are dependent on ash content and mode of disposal.

Where the sludge includes no ash, lime/limestone scrubbing systems appear to have cost advantages over regenerable FGD systems up to sludge disposal costs of about $4 per wet ton. Lime/limestone scrubbing systems no longer appear to be competitive with regenerable FGD systems if sludge disposal costs are greater than about $10 per wet ton, assuming markets are available for the by-products from the regenerable systems.

2. The only alternative regenerable FGD by-products with significant potential markets are H_2SO_4 and elemental sulfur. Elemental sulfur is the most environmentally desirable throwaway product; it has low solubility, substantially reduced storage requirements, and potentially can be marketed at a later date. Technology for sulfur production has been demonstrated in a smelter application, and the technology appears to be transferable to steam generators. Sulfur production in an integrated FGD unit on a utility boiler will not be demonstrated until 1975 (EPA, Wellman-Lord FGD, Allied Chemical sulfur process, Northern Indiana Public Service Company unit).

3. Based on lead time considerations, vendor supply, and marketing considerations, regenerable FGD systems producing H_2SO_4 or elemental sulfur appear to be limited to a maximum of about 40% of the total electric utility FGD systems projected in 1980.

IV. KEY FINDINGS RELEVANT TO TECHNICAL RECOMMENDATIONS

1. Technology is currently available which appears to be capable of minimizing or eliminating potential environmental problems associated with sludge disposal--water pollution and land deterioration. This technology includes closed-loop scrubber system operation, use of liner material at the disposal site, and chemical treatment (fixation). Closed-loop operation is currently being applied at most lime/limestone scrubber installations. Liner materials have been in use, apparently successfully, for many years. Although it hasn't been applied to scrubber sludge disposal, there is no reason to believe liner technology should not be transferable. Fixation technology is currently offered as a commercial process. Based essentially on small scale evaluations and limited full scale data, these technologies appear to be effective in alleviating potential environmental problems. Available costs for liner and fixation technologies applied to sludge disposal cover a broad range.

2. Currently there is a wide range of lime/limestone FGD system applications and sludge disposal approaches. Through these activities, utilities, FGD vendors, and vendors of sludge handling technology can be expected to identify environmental problems and solutions, and to optimize costs of sludge disposal, as necessary for each specific application.

3. To assure greater application and to further minimize the environmental effects of these technologies, at reasonable cost, additional information, primarily from large scale sources, is needed. For untreated sludge disposal, necessary information includes leachate effects on soil substrates, liner materials, and groundwater as a function of time; the effects of run-off or leakage on surface water; the

techniques of effective sludge pond reclamation; and the associated economics of various alternative approaches. For fixated sludge disposal, necessary information includes permeability, leachability, mechanical strength and rewatering tendencies as a function of time for the various available fixation processes; and the associated economics of these processes.

4. A continuing, coordinated EPA program, with expansion of the current program, is required to optimize the environmental effectiveness and to assure reasonable costs for sludge disposal techniques over a wide range of applications. This program will require the evaluation of utility and sludge handling vendor efforts, as well as independent laboratory and field evaluation of disposal processes by EPA.

TECHNICAL RECOMMENDATIONS

After considering the sludge treatment/disposal efforts currently underway by government and industry, the SOTSEP recommends that an expanded and coordinated effort within ORD be established with assignment of adequate responsibilities and resources to the appropriate research, development and demonstration (RD&D) laboratories within the NERC's to accomplish an integrated program plan. The Panel believes such a program is justified on the basis that more data are necessary to assure greater application of flue gas desulfurization and to further minimize environmental effects, at reasonable cost.

The recommended technical program would have the objective of optimizing the environmental effectiveness and assuring reasonable costs for sludge disposal techniques over a wide range of applications. The integrated program plan should contain the following essential elements:*

1. Intermedia Problem Definition

This element consists primarily of chemical and physical analyses of untreated and treated scrubber sludges and associated liquors. It is recommended that the data base be expanded to include sample analyses from more installations representing a broader range of sludges indicative of typical lime/limestone and double alkali process applications. The expansion should include more analyses of sludge materials from lime/Eastern coal, limestone/Eastern coal, limestone/Western coal and double alkali/Eastern coal combinations. It

*Procurement activities for implementation of substantial portions of these elements have been initiated.

would also include analysis of sludges from lime/Western coal, carbide sludge/Eastern coal and limestone/oil.

2. Technology Survey and Small Scale Evaluation

This element consists of the following efforts:

a. Close coordination with utility and vendor sludge treatment/disposal programs: this includes additional survey and information exchange visits to current and future utility and vendor installations with active programs regarding handling, treatment and disposal technology, and economics.

b. Laboratory evaluation of sludges after fixation or other stabilization treatment: this effort includes determination of permeability, leachability, mechanical strength, and other properties of sludges after treatment by various vendors offering commercial processes.

c. Field evaluation of sludge disposal with untreated and treated (fixed) sludge: this effort includes evaluation of an untreated limestone/Eastern coal sludge disposal pond; and evaluation of two simulated landfills, one with lime/Eastern coal sludge and the other with limestone/Eastern coal sludge, each treated (fixated) by two different vendors offering commercial processes. Associated environmental monitoring and analysis of

permeability, leachability, leachate/soil interactions, groundwater effects, and mechanical properties would be performed for all three sites over an approximate two to three year period.

d. Sludge leachate/soil interaction studies: this effort includes correlation of data from the field evaluation above (item c) and extrapolation to other treated and untreated scrubber sludges with representative United States soil.

e. Sludge leachate/liner interaction studies: the effects of treated and untreated scrubber sludge leachates on representative pond liner materials would be evaluated as a function of time.

f. Sludge leachate reuse studies: this effort includes an evaluation of collected sludge leachate for reuse and consideration of an integrated approach encompassing treatment/disposal or reuse of boiler and cooling water blowdown and collected sludge leachate.

3. Large-scale Techno-economic Demonstrations

This element consists of cost sharing of current and/or future large-scale utility programs to evaluate improved handling, treatment, and disposal technology for scrubber sludge and to generate meaningful economic data. Programs would include appropriate environmental monitoring and applications

involving untreated or treated sludges in lined or unlined disposal sites.

4. Policy Formulation

This element involves integration of information from all program elements and formulation of widely applicable guidelines and recommendations for environmentally sound sludge disposal techniques including associated costs.

TECHNICAL DISCUSSION SUMMARY

The following summarizes the most important information obtained by the SOTSEP during the course of its activities.

I. DEFINITION OF THE PROBLEM

A. Availability of Alternative SO_x Control Technology

United States Department of the Interior data indicate that net electric generation by fossil-fueled power plants will increase from 1310 billion Kwh in 1971 to 1950 billion Kwh in 1980. To meet this rapid increase in demand, the electric utility industry will have to consume large additional quantities of fossil fuels. The utilities will have to do this, however, without violating air pollution emission restrictions on sulfur oxides, nitrogen oxides, and particulates. Sulfur oxide restrictions require that the utilities make a choice from among several alternatives. These include low-sulfur fuels, fuel cleaning and conversion, and flue gas desulfurization (FGD).

The amount of natural gas and low-sulfur fuel oil available to electric utilities will be supply-limited at least until 1980. In addition, although abundant low-sulfur coal reserves exist (primarily in the Western States), availability in the near term will be hampered by the mining industry's inability to expand rapidly and the high transportation costs of delivering coal to Eastern and Mid-Western regions where the greatest demand exists. Further, differences between Western and Eastern coal characteristics could cause operating problems in Eastern plants.

Since low-sulfur fuel availability is inadequate, other alternatives for meeting emission restrictions must be considered. Technological developments in fuel cleaning, advanced combusion, and fuel conversion areas have been rapid in the past few years. However, since none of these schemes has advanced past the pilot plant stage, it is unlikely that any of these processes will have a major impact on the supply of low-sulfur fuel in this country before 1980.

For some existing sources, relief from SO_2 emission restrictions may be forthcoming through State action pursuant to EPA's Clean Fuels Policy or through the use of supplementary control systems as an interim measure until adequate constant control measures can be applied. At this time it is uncertain how many utility stations could burn fuel of greater than the currently permitted sulfur content and still meet primary and secondary national ambient air quality standards.

Estimates of economics, availability for application, and utility applicability for alternate technologies are shown in Table 1. It should be noted that these figures were determined as of November 1974. Many sources were used in arriving at the costs shown. While the individual values may not be absolute the relative costs are considered representative. On cost, availability, and applicability bases, the most attractive option for utilities in both near and far term appears to be the installation of a FGD system in conjunction with burning high-sulfur (3 to 5 weight percent sulfur) coal.

For various regenerable FGD processes and lime/limestone scrubbing systems, comparison of the total annualized costs are provided in Figure 1. The cost of lime and limestone scrubbing is shown as a function of sludge disposal costs without ash in Figure 1. Approximate ranges of typical costs of the alternative

Table 1. ECONOMIC ESTIMATES FOR SO_2 CONTROL ALTERNATIVES[a]
(1974 DOLLARS)

SO_2 Control Alternative	Availability For Application	Applicability To Existing & New Power Systems	Fuel Costs (Mills/Kwh)	Capital Costs	Annualized Control Costs (Mills/Kwh)	Effective Fuel Costs (Fuel Cost + Annualized Control Costs)
Low Sulfur Fossil Fuels						
Gas	Current	Limited availability; existing units only.	4.0-6.0	N/A	---	4.0-6.0
Oil	Current	Limited low-S avail.	18.0-20.0	N/A	---	18.0-20.0
Western Coal[b]	Current	Limited prod.; wide applic. to new boilers, limited existing applic.	4.0-6.0	N/A	---	4.0-6.0
Eastern Coal[b]	Current	Limited low-S avail.	4.5-9.0	N/A	---	4.5-9.0
Coal Cleaning						
Physical	Current	Limited: only ~ 25% S removal for most coals.	3.1-6.7[c]	$10/Kw	0.8-1.5	3.9-8.2
Chemical (Pyritic S Removal)	1978	Limited to pyritic coals; full applic. to exist & new.	3.1-6.7[c]	$26/Kw	1.55	4.7-8.3
Desulfurization of Oil						
1 wt % sulfur oil	Current	Full applicability for oil boilers.	15.0[d]	N/A	---	18.0
0.3 wt % sulfur oil	Current		15.0[d]	N/A		20.0
Flue Gas Desulfurization Process						
Double Alkali	1974	Wide applicability to most existing and new coal & oil boilers.	3.1-6.7[c]	$61/Kw	3.55	6.7-10.3
Lime Scrubbing	Current		3.1-6.7[c]	$45/Kw	2.90	6.0-9.6
Limestone Scrubbing	Current		3.1-6.7[c]	$50/Kw	2.86	6.0-9.6
MgO (to H_2SO_4)	Current		3.1-6.7[c]	$53/Kw	3.07	6.2-9.8
Wellman-Lord (to H_2SO_4)	Current		3.1-6.7[c]	$60/Kw	3.67	6.8-10.4
Wellman-Lord (to S)	Current		3.1-6.7[c]	$61/Kw	3.80	6.9-10.5
Cat-Ox	Current		3.1-6.7[c]	$85/Kw	3.44	6.5-10.1
Fluidized Bed Combustion[e]	1977-1978	Applicable only for new systems.	3.1-6.7	$308/Kw[f]	0.3-1.78	3.4-8.4
Coal Gasification						
Low Btu gas	Post 1980	Generally more applicable to new units.	3.1-6.7	$72-$109/Kw	---	8.3-12.8
High Btu gas	Post 1980	Applicable to new & existing units.	3.1-6.7	$75-$125/Kw	---	12+
Coal Liquefaction	Post 1980	Applicable to new and existing units.	3.1-6.7	$60-$90/Kw	---	6.5-9.6

[a] As of November 1974.

[b] Costs are for Western coal delivered in the West and Eastern coal delivered in the East; additional costs for transporting Western coal to the East (or vice versa) are $7.50 per ton per 1000 miles.

[c] Coal cost is for high sulfur (3.0-4.0% S) Eastern coal.

[d] Oil cost is for 3.5-4.0% S crude oil.

[e] Pressurized fluid bed boiler combined cycle, once through system; coal.

[f] Includes power generation equipment.

[g] Control considered inherent in the boiler.

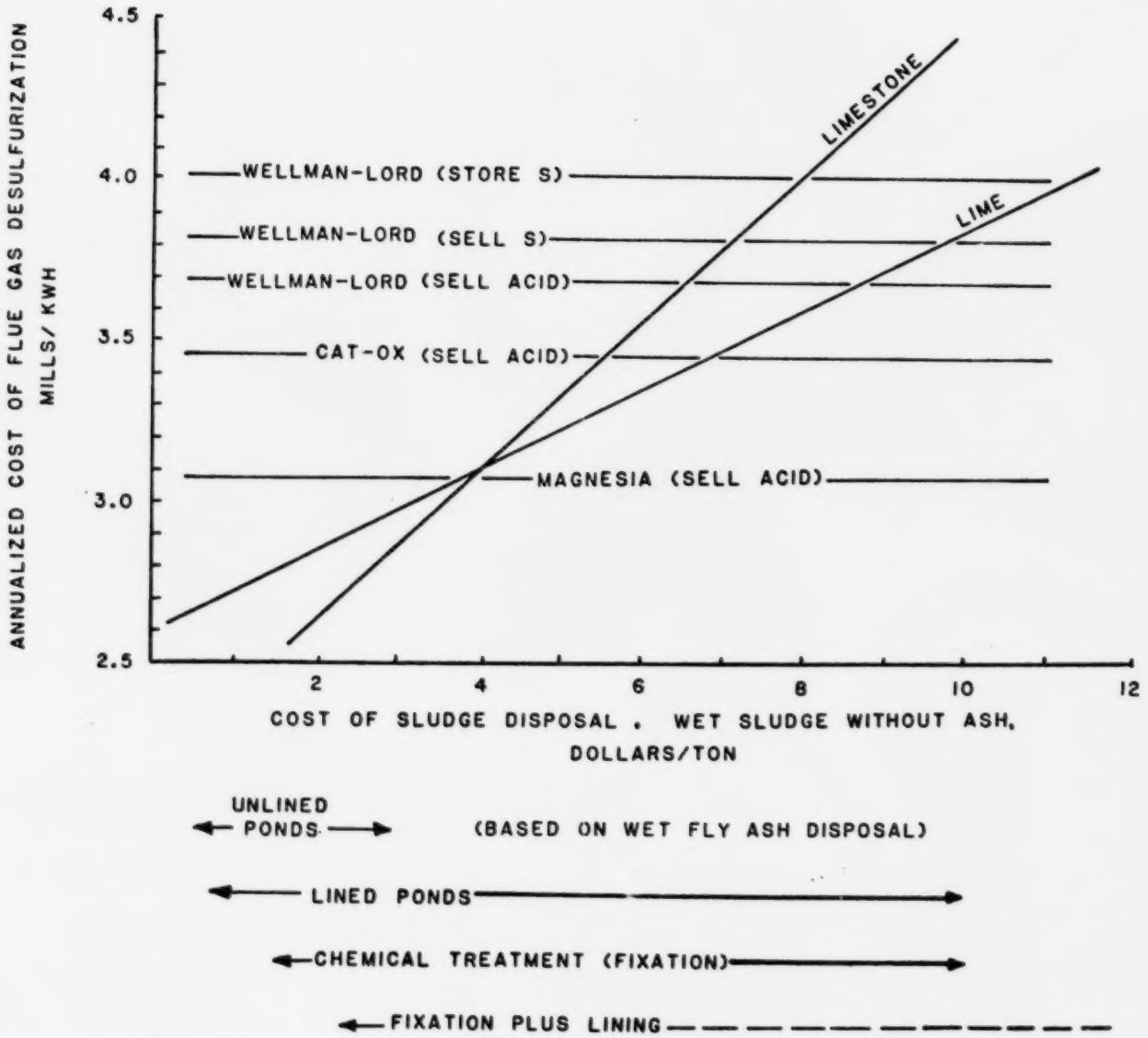

Figure 1. Process Cost Comparison for Non-Regenerable and Regenerable Flue Gas Desulfurization Systems--Effect of Sludge Disposal and By-Product Sales or Disposal (Without Fly Ash).

disposal methods are included. The ranges generally indicate an apparent minimum representing ideal circumstances, and a maximum based on currently available cost data. Additionally, several by-product marketing cases for representative regenerable FGD systems are shown. Inspection of Figure 1 (which includes ash disposal separate from sludge disposal) indicates that neither throwaway nor regenerable FGD systems are clearly preferable although lime/limestone systems have cost advantages over regenerable systems at disposal costs up to about $4/wet ton of sludge. Also, sale of sulfur products (as sulfur or as acid) is important to regenerable systems' competitive position. Above about $7/wet ton for limestone and $10/wet ton for lime scrubbing, these systems no longer appear to be competitive with regenerable FGD systems, assuming there are markets available for by-products from the regenerable systems.

As this figure indicates, lime/limestone FGD annualized costs are strongly dependent on sludge disposal costs which in turn are dependent on the mode of disposal; e.g., lined or unlined ponds, and treated sludge for landfill. For example, for a particular lime scrubber system disposing of sludge without ash, total annualized operating costs would be 2.8 mills/Kwh if sludge disposal costs were $1.5/wet ton of sludge; costs would be about 3.2 mills/Kwh if disposal costs were $5/wet ton of sludge.

Other factors which influence such cost comparisons include local sulfur market conditions, power plant conditions (size, age, percent S fuel, retrofit difficulty, land availability, site variables), and local regulations. Based on current trends, technology availability, and lead time considerations, lime/limestone wet scrubbing will probably comprise the major portion (75 percent) of the total FGD systems installed

by 1980. Because sludge disposal costs are an appreciable fraction of total scrubber annualized costs, it is important that current EPA studies of treatment/disposal costs as a function of power plants and site variables be continued.

B. Potential Demand for Lime/Limestone Scrubbing

Installation of flue gas desulfurization systems in the utility industry is presently demand-limited and is expected to remain demand-limited through 1975. The total generating capacity controlled by the end of 1975 is projected to be no more than 10,000 Mw. Because of regulatory pressures the installation of FGD systems should become supply-limited sometime between 1975 and 1977. From 1977 to 1980 the installation of flue gas desulfurization systems will almost certainly be supply-limited. Based on regulatory pressures and expanding generating capacity coupled with a clean fuels deficit, it is forecast that a maximum of over 130,000 Mw of installed coal-fired generating capacity will need to be controlled by FGD systems by 1980. However, the most likely demand figure by 1980 is estimated at 90,000 Mw of FGD control, or about 35% of total estimated coal-fired generating capacity. In the post-1980 period, depending on the commercial availability and viability of alternate clean fuel technologies, FGD systems could be installed to the extent they approach demand requirements. Recent projections by EPA for the need for coal-fired utility FGD systems are shown in Figure 2.

In the post-1975 period the projected annual rate of application of regenerable FGD is expected to exceed that for the non-regenerable FGD. However, based on current emphasis, technology availability, and lead time considerations, most of the FGD systems installed by 1980 are expected to be lime/limestone. A minimum of 60 percent for lime/limestone has

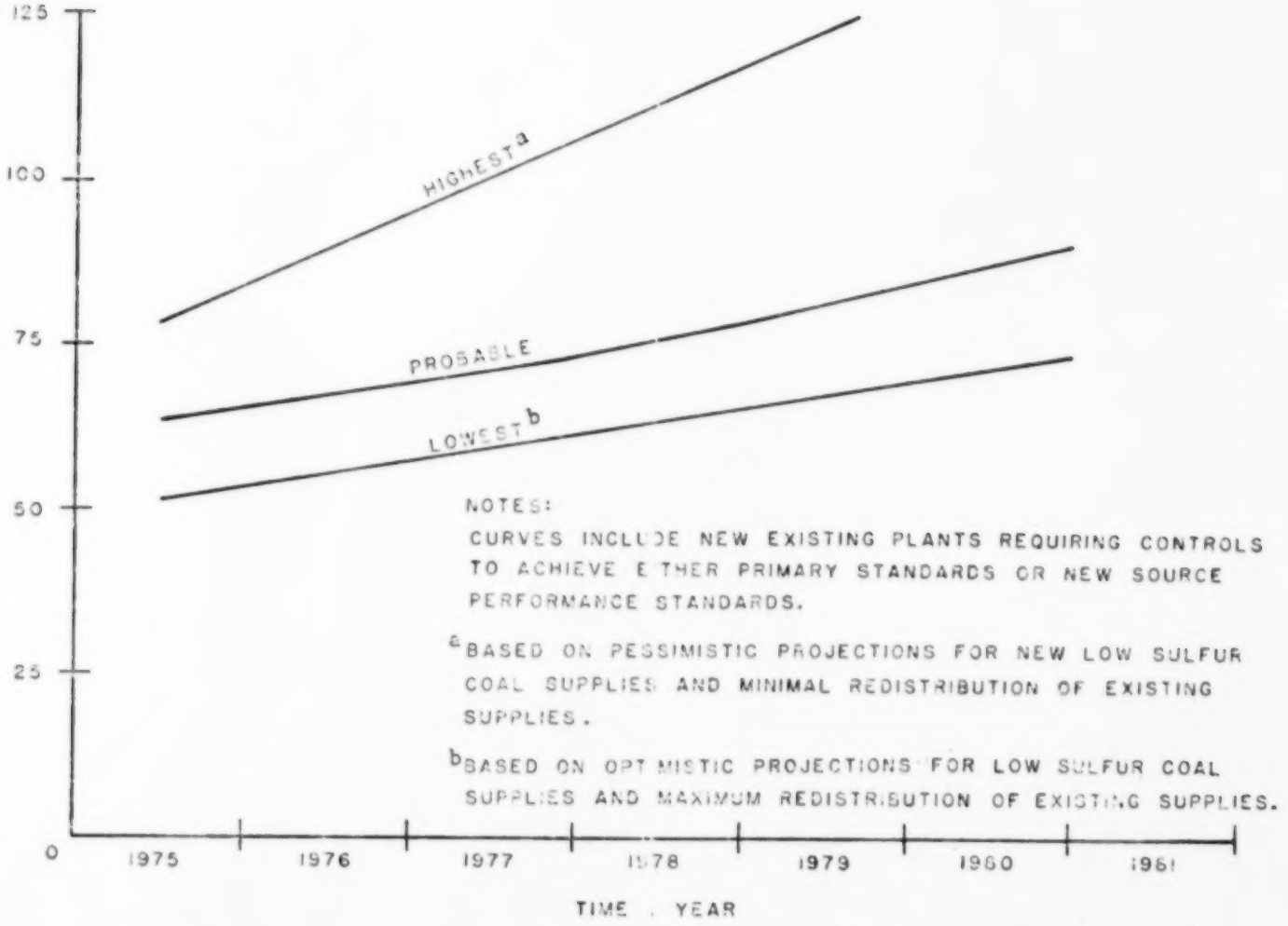

Figure 2. Cumulative Need: FGD for Coal-Fired Power Plants.

been projected, but current trends indicate this figure will be much higher. Other applications of lime/limestone scrubbing (e.g., oil-fired utility boilers, coal-fired industrial boilers) could make an effective figure of 90,000 Mw for control by this system a realistic projection.

C. Quantification of the Problem and Comparison With Analogous Environmental Problems

The necessity to dispose of or utilize large quantities of sulfur removed from the flue gas is inherent in any flue gas desulfurization system. The sulfur compounds produced by flue gas desulfurization systems fall into two general categories: throwaway or saleable products. Lime/limestone and double alkali scrubbing systems generate throwaway sulfur oxide sludge products with little commercial value projected at the present time. Limestone scrubbing processes ordinarily produce sludges containing $CaSO_3 \cdot \frac{1}{2}H_2O$, $CaSO_4 \cdot 2H_2O$, and $CaCO_3$; lime sludges may contain unreacted lime as well.

A power plant SO_2 scrubbing system can be designed with the alternative of collecting flyash simultaneously with the flue gas scrubbing operation or of collecting flyash upstream of the scrubbing operation, using precipitators and/or mechanical collectors. Additionally, the ash may be disposed of with the scrubber sludge or independently of it. As yet, no consistent approach has been taken by the utility industry. For coal-fired installations where efficient particulate removal is not installed upstream of the wet lime/limestone absorber, scrubber sludges can contain large quantities of coal ash.

The amount of sludge generated by a given plant is a function of the sulfur and ash content of the coal, the coal usage, the load factor (on-stream hours per year), the mole ratio

of additive to SO_2, the SO_2 removal efficiency of the scrubbing system, and the moisture content of the sludge. Table 2 shows the effects of variations in the assumed values of these parameters. The values listed in the national average represent a mix of Western and Eastern plants expected in 1980 based on the trends shown by present flue gas desulfurization system orders.

Assuming the projected 90,000 Mw of FGD control is accomplished entirely by limestone installation* using the national average annual sludge production rates per 1000 Mw of controlled generating capacity, the amount of wet sludge and ash (50 percent moisture) that will have to be disposed of annually by 1980 is predicted to be 119,000,000 metric tons/year (131,000,000 tons/year). Depending on the viability and commercial availability of alternate clean fuel technologies, sludge production rates could substantially increase in the post-1980 period.

To put sulfur oxide scrubber sludge into perspective with other wastes, two approaches were taken. The first was to view sludge as part of the land and solid waste impacts associated with a 1000 Mw coal-fired utility unit, thereby assessing intra-industry effects. The second was to compare sludge with wastes from other industries and activities.

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* It is unlikely that all coal-fired utility FGD installations will be lime/limestone systems. However, the majority are expected to be, and other applications (e.g., oil-fired utility boilers, coal-fired industrial boilers) could make the projected sludge production figure quite realistic.

Table 2. TYPICAL QUANTITIES OF ASH AND SLUDGE PRODUCED BY A 1000 MW COAL-FIRED GENERATING STATION CONTROLLED WITH LIME/LIMESTONE FLUE GAS DESULFURIZATION SYSTEMS, SHORT TONS PER YEAR[a]

	Case 1 Base Case	Case 2 Effect of Stoichiometry	Case 3 Effect of SO_2 Removal Efficiency	Case 4 Effect of Coal S	Case 5 1980 National Average
Coal Ash, dry	338,000	338,000	338,000	282,000	338,000
Coal Ash, wet (80% solids)	423,000	423,000	423,000	354,000	423,000
Limestone Sludge, dry					
$CaSO_3 \cdot 1/2H_2O$	322,000	322,000	286,000	64,000	261,000
$CaSO_4 \cdot 2H_2O$	48,000	48,000	42,000	10,000	39,000
$CaCO_3$ unreacted	185,000	92,000	216,000	37,000	92,000
Total	555,000	462,000	544,000	111,000	392,000
Limestone Sludge, wet (50% solids)	1,110,000	924,000	1,090,000	222,000	784,000
Limestone Sludge, wet (with ash)	1,790,000	1,600,000	1,760,000	786,000	1,460,000
Lime Sludge, dry					
$CaSO_3 \cdot 1/2H_2O$	322,000	322,000	286,000	64,000	261,000
$CaSO_4 \cdot 2H_2O$	48,000	48,000	42,000	10,000	39,000
CaO unreacted	52,000	17,000	69,000	11,000	22,000
Total	422,000	387,000	397,000	85,000	322,000
Lime Sludge, wet (50% solids)	844,000	774,000	794,000	170,000	644,000
Lime Sludge, wet (with ash)	1,520,000	1,450,000	1,470,000	734,000	1,320,000

[a] Assumptions:

Coal:	% S	3.5	3.5	3.5	0.7	3.0
	% ash	12	12	12	10	12
Plant:	hr/yr	6400	6400	6400	6400	6400
	lb coal/Kwh	0.88	0.88	0.88	0.88	0.88
Scrubber:	% SO_2 removal	90	90	80	90	85
	CaO/SO_2 mole ratio	1.2	1.0	1.2	1.2	1.0
	$CaCO_3/SO_2$ mole ratio	1.5	1.2	1.5	1.5	1.2
	% sulfite oxidation	10	10	10	10	10

As shown in Table 3, the annual land and solid waste impact of a 1000 Mw coal-fired electric energy system equipped with flue gas desulfurization (FGD) for SO_x and particulate removal is 12,000 to 14,000 hectares (30,000 to 35,000 acres), depending on the type of coal mining (deep or surface) used. The coal mining operations appear to have the greatest impact in terms of land use and environmental effects. Although the right-of-way required for transmission lines actually consumes more land than coal mining, this right-of-way land is still available for other uses, public or private, and aside from aesthetics, the environmental effects are minimal.

A plant equipped with a lime/limestone FGD system and using ponding for disposal would require just over 2 times as much total area as a plant site without the SO_x and particulate control system. For comparison, this same plant would require about 1.5 times the total area of a plant with particulate control only and ash disposal by ponding. This increase in area (which may be at the plant site or at some remote location) is required for the disposal of the solid wastes generated by the FGD system.

Table 3 also shows that large quantities of wastes are involved in coal mining and processing operations. It can be seen that the FGD system will produce quantities of wastes about 3 times greater than for deep mines, but about half that for strip mines.

Table 4 presents a semi-quantitative comparison of major U.S. solid wastes on an as-disposed-of basis. In addition to quantities of wastes, typical compositions, disposal methods, potential environmental problems, and disposal costs are shown. Quantities are not directly comparable since they are based on many different sources and time periods.

Table 3. COMPARATIVE LAND AND SOLID WASTE IMPACT OF 1,000 MW ELECTRIC ENERGY SYSTEM (0.75 LOAD FACTOR)

(LOW LEVELS OF ENVIRONMENTAL CONTROLS EXCEPT FOR INSTALLATION OF A LIMESTONE FGD SYSTEM FOR SO_x AND PARTICULATE REMOVAL)

	Mining (Coal)		Processing	Transport	Conversion (Plant Site)	Limestone FGD System, Untreated Ponded Sludge[a]	Transmission	Totals	
	Deep	Surface						Deep	Surface
Land Affected, acres[b]	9,120	14,010	161	2,213	350	367 (30 ft depth)	17,188	29,399	34,289
Annual Solid Waste Produced, short tons	97,141 (wet, 97% solids) (101,346 with acid drainage sludge)	2,762,000 (wet, 98% solids) (2,762,328 with acid drainage sludge)	454,092 (wet, 99% solids)	0	0	1,460,000 (wet, 50% solids)	0	2,011,233	4,676,092
Environmental Impact	1) Potential land degradation due to subsidence; 2) Acid mine drainage water pollution problems	1) Mined land made barren precluding wildlife habitat, recreation and most other uses; 2) Acid mine drainage water pollution problems	1) Culm piles; 2) Water pollution: a) acid drainage; b) siltation; 3) Air pollution: a) discharges SO_2, CO & H_2S; b) potential spontaneous combustion	Use of land for railroad beds	Use of land for power plant site	1) Potential groundwater pollution problems; 2) Land potentially made useless if sludge not treated or permanently dewatered	Use of land for transmission line right of way	N/A	N/A
Typical Technique(s) Available to Minimize Impact	1) No well developed cost-effective technology to control subsidence; 2) Neutralization of mine drainage with lime	1) Intensive land reclamation can restore most strip-mined land; 2) neutralization of mine drainage with lime	Compacting in holes, mines, quarries, etc.	N/A	N/A	1) Although reclamation is feasible, no well developed, cost-effective technology has been demonstrated; 2) Sound pond management, use of impermeable pond liner, and operation of FGD system in closed-loop mode can minimize water pollution. (As an alternative to ponding, chemical fixation and landfill appears to have potential for solving both water pollution and land reclamation problems.)	N/A	N/A	N/A

[a] See Table 2, Case 5, for assumptions (also includes ash).

[b] Land affected is expressed as a time average of the amount of land in use over 30 years. Fixed land is taken at its full amount; average variable use (waste storage) is 15 times the annual incremental damage.

Table 4. COMPARISON OF MAJOR SOLID WASTE DISPOSAL PROBLEMS[a]

Waste Material	Quantity Disposed Annually in Referenced Year (metric tons, as disposed of)	Composition	Method of Disposal	Land Use or Reclamation Considerations	Environmental Problems with Minimal Pollution Control	Estimated Disposal Costs ($/ton)
Municipal and Industrial Refuse[b]	360,000,000 (1973) (75% solids)	40% municipal refuse, 60% industrial refuse Typical Composition: paper waste (44%); food waste (8%); glass and ceramic wastes (9%); garden waste (8%); rocks, dirt, etc. (4%); plastics, rubber, leather, textile, wood wastes (8%).	Landfills, incineration	Cover material needed to support vegetation	Undefined groundwater & surface water pollution; potential air pollution (incinerator emmissions, odor)	1-4 (landfill) 5-12 (incineration)
Culm Piles[c]	>91,000,000 (1969) (dry basis)	Waste coal, slate, carbonaceous & pyritic shales, clay, trace metals	Surface piles, landfills	Cover material required for plant growth. Provision for collection of drainage	Undefined water pollution; siltation; acid drainage; possible air pollution (odor); spontaneous combustion	0.30-0.50
Mineral Ore Wastes[d]	1,300,000,000 (1970) (dry basis)	Rock waste from mining operations	Surface piles, landfills	Needs cover material	Undefined groundwater & surface water pollution	<0.50
Coal Ash	95,000,000[e] (1980) (80% solids)	Solids Composition (wt.%) SiO_2 (30-50), Al_2O_3 (20-30), Fe_2O_3 (10-30), CaO (1.5-4.7), K_2O (1-3), MgO (0.5-1.1), Na_2O (0.4-1.5), TiO_2 (0.4-1.3), SO_3 (0.2-3.2), C (0.1-4.0), B (0.1-0.6), P (0.01-0.3), and trace metals	Ponding, landfills	Needs cover material	Undefined groundwater and surface water pollution	0.50-3.00 (exclusive of pond construction costs)
Limestone Scrubber Sludge (excluding coal ash)	64,000,000[f] (1980) (50% solids) (119,000,000 including ash)	Solids - generally mixtures of $CaSO_3 \cdot \frac{1}{2}H_2O$, $CaSO_4 \cdot 2H_2O$, and $CaCO_3$ Liquor - contains various amounts of dissolved species which originate in the coal, alkali, and makeup water	Ponding, landfills	Untreated sludge difficult to dewater	Potential groundwater & surface water pollution	2.50-4.50/wet ton (ponding) 2-10/wet ton (fixation and landfill)

Table 4 (Continued). COMPARISON OF MAJOR SOLID WASTE DISPOSAL PROBLEMS[a]

Waste Material	Quantity Disposed Annually in Referenced Year (metric tons, as disposed of)	Composition	Method of Disposal	Land Use or Reclamation Considerations	Environmental Problems with Minimal Pollution Control	Estimated Disposal Costs ($/ton)
Municipal Sewage Sludge	55,000,000 (1980) (0.1-20% solids)	Composition of Raw Primary Sludge, %: Volatile matter - 60-80 Ash - 20-40 Insoluble ash - 17-35 Greases & fats - 7-35 Protein - 22-28 NH_4NO_3 - 1-3.5 P_2O_5 - 1-1.5 Cellulose - 10-13 Trace metals	Ponding, landfills	Hard to dewater, difficult to develop	Undefined groundwater & surface water pollution; potential air pollution	0.50-10
Phosphate Rock Slime[g]	760,000,000 (1970) (4-6% solids)	Solids Composition (wt.%) P_2O_5 (9-17), Al_2O_3 (6-18), SiO_2 (31-46), CaO (14-23), Fe_2O_3 (3-7), MgO (1-2), CO_2 (0-1), F (0-1), BPL (19-37), LOI (9-16), trace metals	Ponding	Hard to dewater (settles to only 30% solids after years). Not established that dried solids will support vegetative growth.	Undefined groundwater & surface water pollution	0.03-0.05
Phosphate Fertilizer Sludge[h]	5,200,000 (1972) (1-5% solids)	Typical Solids Composition (wt.%) $CaSO_4$ (40), MgO (1), $MgSO_4$ (5), Fe_2O_3 (15), CaO (3), Mn_2O_3 (4), SiO_2 (20), Al_2O_3 (12), trace metals	Ponding	Hard to dewater	Undefined groundwater & surface water pollution	0.04-0.25
Gypsum From Fertilizer Manufacture[g]	28,000,000 (1973) (85-90% solids)	Chiefly $CaSO_4 \cdot 2H_2O$	Ponding, surface piles	Needs cover material to support vegetation & make aesthetically acceptable	Undefined groundwater & surface water pollution	--

Table 4 (Continued). COMPARISON OF MAJOR SOLID WASTE DISPOSAL PROBLEMS[a]

Waste Material	Quantity Disposed Annually in Referenced Year (metric tons, as disposed of)	Composition	Method of Disposal	Land Use or Reclamation Considerations	Environmental Problems with Minimal Pollution Control	Estimated Disposal Costs ($/ton)
Taconite Tailings	1,100,000,000[i] (1971) (4-5% solids)	Typical Solids Composition (%): Fe - 15 Si - 33 Al - 0.35 Ca - 1.67 Mg - 2.55 Mn - 0.37 Ti - 0.030 P - 0.026 Na - 0.20 K - 0.08 S - 0.03 C - 0.11 H - 0.10 O - 46.40 Trace elements	Ponding, lake dumping (Reserve Mining Co.)	Fertilization, mulching, etc. required for reclamation of ponds	Potential ground and surface water pollution	0.005-0.05 (lake dumping)

(a) For references, see Volume II, Table I-10.
(b) Exclusive of agricultural and mining wastes.
(c) Bituminous coal only.
(d) Mining wastes from metal and non-metallic ores, exclusive of fossil fuels; no processing wastes included.
(e) Assumptions: 12% ash, 6400 hr/yr, 248,000 Mw installed coal-fired generating capacity (1980), 0.4 kg coal/Kwh.
(f) Assumptions: 3% S, 12% ash, 6400 hr/yr, 90,000 Mw controlled generating capacity, 85% SO_2 removal, 0.4 kg coal/Kwh, 1.2 $CaCO_3/SO_2$ (inlet) mole ratio, 10% oxidation
(g) 80% disposed of in Florida.
(h) Most acid mine drainage comes from abandoned mines and receives no treatment.
(i) Assumptions: >100 million tons crude taconite ore annually, 25% average iron content, 60% beneficiation.

Comparison of quantities of solid waste generated by various industries provides a means of placing projected figures for scrubber sludge production into perspective. Two bases of comparison can be made: quantification on a wet basis (or as disposed of) represents the magnitude of waste actually handled by the industry, while a dry basis serves as a more uniform basis of comparison. Both techniques indicate that waste disposal problems similar in magnitude to that posed by scrubber sludge are dealt with by several industries.

Considering the quantities of wastes disposed of on a wet or as-disposed-of basis, of those wastes surveyed in Table 4 several are generated in significantly greater amounts than projected 1980 scrubber sludge. Both mineral ore wastes and taconite tailings production rates are approximately an order of magnitude greater than the projected sludge production rate, while phosphate slimes, municipal/industrial refuse, coal ash from coal-fired utilities, and culm pile material also greatly exceed sludge in amounts generated. Total projected sewage sludge, gypsum from phosphate fertilizer manufacture, and acid mine drainage sludge production quantities are less than that of projected scrubber sludge.

As is the case for scrubber sludge, ponding and landfilling provide the major mechanisms of disposal for most waste products. In terms of land use and reclamation, and potential surface water and groundwater pollution, these disposal mechanisms have many points of similarity for the various industries. In some cases, land use for waste disposal has destroyed wildlife habitat and is aesthetically objectionable. In addition, all wastes have the potential for varying degrees of surface and groundwater pollution depending on their chemical compositions and solubilities, and the location, design, and operation of the

disposal site. With proper site selection and design (possibly including a permanent impermeable liner) and sound operating practices, however, surface water and groundwater pollution can be avoided.

To reclaim the disposal site, most of the stable wastes require only a cover material to support growth of vegetation and to prevent eventual erosion of the wastes by run-off water. However, some wastes (phosphate rock slime, sewage sludge, untreated scrubber sludges) are very resistant to dewatering and could reslurry in the pond or landfill. In some cases, these disposal sites could become only temporary storage sites which could present deferred disposal problems as well as difficult land reclamation problems. Fixation technology, now commercially available and applied at several full-scale installations, appears to be a successful approach to land reclamation. In Florida, reclamation of slime ponds has been successfully achieved using tailings from the flotation process to aid in dewatering. Another type of approach to the potential land use problem is based on production of a sludge more amenable to landfill disposal by an oxidation process.

Costs for waste disposal vary greatly depending on the treatment and transportation of the wastes. Disposal costs are minimal for phosphate rock slime and similar wastes which typically are not treated, are disposed of near the plant site, and have little land reclamation activity. The projected cost range for disposal of scrubber sludge is broad. The low end represents no treatment and onsite disposal in an unlined pond. The high end represents steps to solve both the land reclamation and water pollution problems by chemical treatment and transportation to an off-site landfill. Discharge of scrubber sludge to a lined pond solves the water pollution problem only and, based on available data, typical costs would be in the range of $2.50-4.50/wet ton.

In summary, based on preliminary comparisons of available information on quantities, compositions, and current disposal methods, untreated scrubber sludge disposal may produce an environmental impact somewhat analogous to those associated with other solid wastes such as culm piles, municipal sewage, municipal and industrial refuse, and coal ash. Significant quantities of scrubber sludge are projected for 1980, but waste disposal problems of similar and larger magnitudes have been dealt with by industry for many years. Although the total environmental impact associated with disposal of untreated scrubber sludge in a soil-lined disposal area is not well-defined, currently available technology has the potential for environmentally acceptable disposal. Furthermore, solutions to achieve satisfactory disposal will be influenced by emerging environmental restrictions. Research efforts to thoroughly evaluate potential hazards and available technology is continuing through government-funded contractors, utilities, and fixation technology vendors.

D. Relationship Between Sulfur Oxide Scrubber Sludge, Standards/Regulations, and Enforcement

In promulgating New Source Performance Standards for steam generators and guidelines for State implementation plans, the effects of flue gas desulfurization systems were considered, including the generation of sludges. However, in 1971 when these actions were taken, there had been little experience in processing the relatively small quantities of sludges that were being generated. EPA had considered the problem; no deleterious effects were traced to sludge disposal, but the potential for groundwater and surface water contamination was recognized. It was judged that the sludge was similar to other wastes that were being generated by U.S. industries and could be handled using

techniques that were known, even if they hadn't been applied to full-scale installations.

In the past 2 years, the electric utility industry has indicated dissatisfaction with SO_2 restrictions in general and the applicability of flue gas desulfurization systems in particular. At the October-November 1973, EPA enforcement hearings on power plant pollution control, several utilities cited adverse environmental effects of sludge disposal and costs as principal obstacles to the installation of flue gas desulfurization systems. Legal challenges from utilities have primarily questioned the adequacy of scrubbing technology, particularly system reliability, and the necessity for sulfur oxide control. However, sludge disposal aspects have been cited and, specifically, environmental impact statements documenting EPA consideration of associated environmental problems have been an issue.

The impact of the enacted Federal Water Pollution Control Amendments (FWPCA) of 1972 and the proposed Solid Waste Management Acts on scrubber sludge disposal cannot be fully evaluated at this time. However, implementation of both acts requires EPA to issue guidelines and limitations regarding water discharge and waste disposal. These guidelines will be issued and periodically updated on the basis of best available control technology. In the Federal Water Pollution Control Act Amendments of 1972 Congress stated that the national goal was to eliminate the discharge of pollutants into all waters. The act appears to encompass any pollutant discharge with the potential for degrading water quality directly through seepage, discharge, or run-off, or indirectly through groundwater contamination. The Safe Drinking Water Act of 1974 strongly addresses the need for protection of groundwater supplies. It is apparent that the approach Congress is taking is the elimination or minimization of

discharges into surface waters and ground waters. In view of legislative restrictions it appears that it will be necessary to prevent or control leaching to the ground or surface waters. Typically, lime/limestone systems are designed to operate in a closed-loop mode, which means that there is no direct discharge of liquor from the system. A certain amount of liquor is contained in the system's waste sludge; however, proper disposal methods can prevent leaching of this liquor to the natural water system. Additional information concerning the chemical and physical characteristics of the wide variety of FGD systems and associated scrubber liquors and sludges will insure responsible implementation of legislation. Programs which are planned and underway will provide this necessary information.

E. Nature of the Material

A limited amount of data is available on the chemical nature of various scrubber sludge materials; these data can be used to help quantify potential environmental effects of sludge disposal. Sludges from different units exhibit a wide variation in chemical properties, but are generally mixtures of $CaSO_3 \cdot \frac{1}{2}H_2O$, $CaSO_4 \cdot 2H_2O$ (gypsum), $CaCO_3$ (limestone), and fly ash in varying proportions.

No definite industry trends have been observed regarding ash collection and disposal, separately or in conjunction with SO_2 scrubbing and sludge disposal. At this time, there is insufficient information on which to base these decisions. However, since fly ash disposal has been practiced by utilities for many years, fly ash characteristics provide a reference point for comparison with sludges. Some qualitative comparisons of ash and scrubber sludge are presented below:

1. The solid phase of scrubber sludge will consist essentially of the calcium compounds noted above. These calcium compounds have a limited solubility in sludge liquors. The major components in fly ash are even less soluble.

2. Scrubber sludge and ash solids will contain trace elements originating in the coal. Based on data available at this time, the major source of heavy metal concentrations in sludge is the coal. Trace elements and other species may also originate in the limestone or lime, the make-up water, and ash sluice water, but their contribution to the total trace element content of the sludge is minor.

3. Sludge and ash liquors will contain dissolved species from the solid constituents in accordance with solubilities which are generally an inverse function of pH. The chemistry of the coal, particularly chlorine and sulfur content, and the type of scrubber system employed will determine the pH of the untreated sludge liquors.

4. Liquors associated with scrubber sludge may also contain species such as chlorides and certain trace metals which are volatilized during coal combustion and removed in the scrubber. These species are generally unaffected by dry ash collection techniques so they are emitted to the atmosphere and not found in the ash liquor. This indicates the multi-pollutant control potential of FGD systems.

5. Limited data indicate total dissolved solids (TDS) vary widely in sludge liquors and ash liquors. Levels for scrubber sludge liquors tend to be considerably higher, in some cases by an order of magnitude or more. These higher TDS values include calcium compounds, magnesium compounds, trace elements and chlorides.

In summary, a qualitative comparison of soluble species found in sludge liquors with those found in ash liquors indicates that sludge liquors would contain greater concentrations of total dissolved solids and levels of major species (e.g., sulfate, chloride, carbonate, calcium and magnesium). Relative levels of trace elements will depend, however, on the chemistry of the coal burned and the type of scrubbing system employed. Limited preliminary data on chemical analysis of sludge liquors, compared to drinking water standards (a stringent basis for comparison), indicate that some sludges may have excessive amounts of one or more of the following: manganese, lead, copper, cadmium, selenium, boron, nickel, magnesium, chloride, sulfate, and total dissolved solids. Some of these and other liquid-phase soluble species are potentially harmful, and would result in potential water pollution problems if they entered surface or groundwater in sufficient concentrations.

Many variables (coal, limestone, make-up water, operating parameters) can influence the quantities of the soluble species. More information is needed to quantify the variable effects, and to better define the chemical characteristics of sludge from large continuously operating systems.

There is wide variation in physical properties for sludges from different units. These properties are influenced by many system variables including the percentage of fly ash and the calcium sulfite/sulfate ratio. The physical properties strongly influence the ease with which the material can be handled and transported, and type and degree of the land reclamation problems for abandoned sludge disposal sites. The main problem relating to physical properties of sludge is difficulty in dewatering. In addition, the results of some preliminary studies indicated a tendency for sludge to rewater to its original water content.

Test data show that the sludges are thixotropic in nature and have retarded settling characteristics. The influence of ash content on settled density of sludge is not well understood. This information could bear upon a decision regarding separate or combined disposal of ash and sludge. Normal pond settling with untreated material will probably result in a final settled density of less than 50% solids. At 50% solids, sludges have low bearing capacity and compressive strength. Preliminary results from bench-scale studies indicate that untreated sludges show a tendency to rewater after being subjected to a dewatering operation (e.g., drying) then exposed to water (rainfall). This characteristic would tend to thwart attempts to increase the final settled density by employing a dewatering unit operation alone.

II. APPROACHES TO DISPOSING OF OR UTILIZING SCRUBBER SLUDGE MATERIALS

A. Commercial Utilization

Investigations of the potential commercial utilization of power plant desulfurization sludges have been made by numerous government and private organizations. These organizations include Federal agencies; research centers; universities; commercial research, processing and sales corporations; national trade associations, and private researchers. The results of their efforts have been disseminated through symposiums, technical reports, newspapers, and periodicals. A review of these references indicates that the consensus of those most knowledgeable about the potential utilization of desulfurization sludges is that, although some commercial usage is feasible from a technical and economic standpoint, the potential outlet is so small that the vast majority of the sludges will not be marketed.

Attempts have been made to develop technology to apply sludges to the existing ash product market or to develop new applications in which the sludge might be used. Such developments and investigations have been reported by research centers including West Virginia University's Coal Research Bureau, Combustion Engineering, and IU Conversion Systems, Inc. These developments include mineral wool, bricks, sintered concrete products, soil amendment, sulfur recovery, gypsum, mineral recovery, road base materials, parking lot materials, artificial aggregate, lightweight aggregate, and aerated concrete.

It was eventually recognized that, despite the many potential fly ash products with quality equal to or superior to existing materials, the use of fly ash was extremely limited; it was also recognized that the situation would be even worse for sludge. Major inhibitions to the use of sludge include highly variable chemical and physical properties, high transportation costs, requirement for dewatering for many applications, and inability to economically compete with other materials.

It is therefore concluded that, at least through 1980, disposal should be the major consideration for the handling of throwaway sludges on a nationwide basis.

B. Present and Planned Utility Industry Disposal Programs

The major options for sludge disposal are ponding and landfill. Table 5 summarizes dewatering techniques and ultimate disposal modes for 15 lime and limestone FGD systems at utility sites; it can be observed that utilities are selecting ponding over landfill as an ultimate disposal mode by a ratio of about 3:2. For those sites selecting the landfill mode, dewatering techniques (such as filtering or centifuging) and/or sludge fixation processes have been or will be used to attempt to produce an acceptable landfill material.

The wide variety of approaches indicated may be based on factors such as: non-uniformity of local regulations; disposal site location and ownership; disposal site proximity to ground or surface waters; soil permeability; variations in chemical and physical properties of sludge; variations in scrubber processes and types of ash collection and disposal.

Table 5. SLUDGE TREATMENT/DISPOSAL TECHNIQUES FOR SELECTED UTILITY LIME/LIMESTONE FGD SYSTEMS
(C = Current; P = Possible Additions)

Facility (Availability Status)	Sorbent / Fuel	Scale	Dewatering Technique					Final Disposition	
			Clarifier	Filter	Centrifuge	Dryer	Pond	Ponding	Landfill
TVA-Shawnee (Current)	Limestone & lime / Eastern coal	Prototype	C	C	C			C (Unlined)	
City of Key West-Stock Island (Current)	Limestone (coral marl) / Residual oil	Full					C		C (Unfixed)
Commonwealth Edison Co.-Will County (Current)	Limestone / Eastern coal	Full	C	P		P	C (Clay lined, well points)		C (Fixed)
Southern California Edison-Mohave Lime: Current Limestone: Oct 1974	Limestone & lime / Western coal	Full	C	C				C (Fixed)	
Kansas City Power & Light-Hawthorn (Current)	Boiler injected limestone / Coal (possible E&W blend)	Full	C				C (Well points)	C (Unlined)	
Kansas Power & Light - Lawrence (Current)	Boiler injected limestone / Eastern coal	Full					C	C (Unlined)	
Louisville Gas & Electric Paddy's Run (Current)	Carbide sludge ($Ca(OH)_2$) / Eastern coal	Full	C	C					C

Table 5 (Continued). SLUDGE TREATMENT/DISPOSAL TECHNIQUES FOR SELECTED UTILITY LIME/LIMESTONE FGD SYSTEMS

(C= Current; P = Possible Additions)

Facility (Availability Status)	Sorbent / Fuel	Scale	Dewatering Technique					Final Disposition	
			Clarifier	Filter	Centrifuge	Dryer	Pond	Ponding	Landfill
Northern States Power - Black Dog (Current)	Limestone / Western coal	Pilot	C					C (Unlined)	
Kansas City Power & Light - LaCygne (Current)	Limestone / Eastern coal	Full						C (Unlined)	
Arizona Public Service - Cholla (Current)	Limestone / Western coal	Full						C (Unlined) (Solar evap)	
Duquesne Light - Phillips (Current)	Lime / Eastern coal	Full	C				C (Curing) (Unlined)		C (Fixed)
Detroit Edison - St. Clair (Jan. 1975)	Limestone / Eastern coal	Full					C		C (Unfixed)
TVA - Widows Creek (1976)	Limestone / Eastern coal	Full					C	C (Unlined)	
Ohio Edison - Bruce Mansfield (1975/1976)	Lime / Eastern coal	Full	C						C (Fixed)
Northern States Power - Sherburne (1976/1977)	Limestone fly ash / Western coal	Full	C					C (Clay lined)	

Several utilities are evaluating the environmental acceptability of their approaches to sludge treatment/ disposal. However, specific details of the monitoring programs are not publicly available. For example, of the utilities listed in Table 5, three appear to be monitoring or planning to monitor their treatment/disposal approaches.

Commonwealth Edison (Will County) - Treated sludge material will be stored in clay-lined basins with groundwater wells. The material will cure for approximately one month and will be inspected by local authorities to obtain permission for offsite disposal. The criteria for permission are unknown at this time. Data are not currently available. Adequate determination of the technical quality of the fixed material and attendant costs is not expected for at least one year.

Kansas City Power & Light (Hawthorn) - Fourteen well points are placed around the unlined on-site pond and are sampled periodically. No definite data are available but it is believed that results to date are inconclusive because the general area may be heavily contaminated by the absorption of leachates from fly ash ponds on the plant site.

Duquesne Light Company (Phillips) - After curing for about 30 days in lined basins, the treated sludge will be dredged out and hauled to a disposal demonstration site about one mile away. The site will include one unlined pond and two ponds lined with Hypalon. Each pond will have underdrainage and overdrainage piping

provisions to collect water for testing. Specific analyses to be performed are not currently known. Results of the field tests are not expected to be available for at least one year.

Neither the utilities nor the sludge conditioning processors are expected to readily identify all environmental problems, solutions, or economics associated with sludge disposal. In all likelihood, detailed information will be especially difficult to obtain from those utilities with a sludge disposal problem, because of concern for regulatory pressures. An EPA program for testing and evaluation of sludge treatment/disposal techniques is necessary to upgrade the environmental effectiveness and cost-effectiveness of these techniques and to correlate information with that obtained from utilities or sludge conditioning processors.

C. Disposal by Ponding

Disposal of wastes by ponding historically has been a favored technique in a number of industries; e.g., gypsum sludge from fertilizer plants, phosphate slime from phosphate mining, and ash from coal boilers.

The mechanics of pond construction and operation are well known. However, many current pond operating techniques were established with less regard for environmental effects than is now considered appropriate (although they are not representative of the best available control technology). There are two major environmental aspects associated with ponding of sulfur oxide sludges which require consideration:

1. The water pollution potential associated with soluble species in the sludge liquor and solid phases.

2. The land deterioration associated with non-settling sludges.

Ponding of SO_x scrubber sludges will require particular attention to proper design and operating practice because of the potential for groundwater pollution. However, leaching of contaminants to an aquifer from a pond can be avoided through proper site selection (considering topography, geology, soil permeability, distance to water table, etc.) and a permanent pond lining. Overflow of pond liquor into surface water can and should be avoided. This will require proper pond design or total recycle of pond liquor, with treatment of any blowdown (purge) streams. The construction and lining of ponds is established technology.

Costs for these water pollution controls are based on estimates for installed pond linings, exclusive of excavation. Installation of a clay lining may vary from $1.80 per square meter ($1.50 per square yard) or higher, depending on the hauling distance. Synthetic liners also vary widely in cost. For small ponds, 0.4 to 4.0 hectares (1 to 10 acres), thin synthetic membranes cost approximately $1.20 per square meter ($1.00 per square yard) while 30 mil fabric reinforced rubber is priced at $7.90 per square meter ($6.60 per square yard). Cost savings can be realized for larger ponds. Based on the assumption given in Case 5, Table 2, $1.20 per square meter ($1.00 per square yard) is equivalent to about $4/Kw capital cost. A general cost range for a total ponding operation, exclusive of future reclamation costs, is $2.50-4.50 per ton of wet sludge (50% solids). Based on the same assumptions referred to above, this range is equivalent to 0.6-1.0 mills/Kwh.

The requirements of liner materials for sludge or ash disposal applications and consequently their cost-effectiveness are not well defined. For example, before the long term effects of sludge or clay as a liner for sludge can be determined with confidence, more information must be developed. As indicated

in Section II.B., several sludge disposal applications of clay linings and one Hypalon application are known.

A potential problem would be the eventual reclamation of the pond site due to resistance to dewatering exhibited by unstabilized sludges. This problem would be particularly difficult to solve in those areas with high annual rainfall and low annual evaporation. Oxidation of the sulfite-laden sludges is currently under development as one approach to enhance dewatering. Another approach is based on treating (fixing) the sludges prior to final disposition to produce a dewatered, solid, load-bearing material. Such a treatment step would result in the pond being used as a landfill site. Pond reclamation schemes such as covering an abandoned site with soil may be possible, although the technology, effectiveness, and costs of reclamation of sludge ponds have not been well defined.

D. Disposal by Landfill

Landfill techniques involve the disposal of sludge treated via dewatering and/or fixation techniques. This technology aims to produce a material with physical and chemical properties which enable environmentally acceptable disposal as landfill without excessive costs. A dewatering step is necessary since slurries from the scrubber circuit are ordinarily only 5-15 percent solids by weight and must be dewatered either for direct landfilling or preparatory to a fixation treatment process followed by landfilling. Varying degrees of pilot plant, prototype, and commercial experience have been obtained on thickeners, vacuum filters, and centrifuges. They have indicated varying degrees of effectiveness in dewatering capabilities. Generally, due to the poor free-settling properties of sulfur oxide sludges, thickeners are limited to dewatering to a maximum

of about 45-50 percent solids, although 65 percent solids was in one case. At this solids density, the sludges behave as a thixotropic liquid. Vacuum filters and centrifuges have been effective in dewatering scrubber sludges to a solids content of up to 55-65 percent by weight. At this solids density, physical properties of the sludge approach those of a solid. Although pressure filters are being evaluated with municipal sewage sludge, their applicability to scrubber sludge has not been assessed. Further data will be necessary before it can be concluded that a vacuum filter, a centrifuge, or possibly a pressure filter is the most favorable dewatering equipment for sulfur oxide sludges.

Chemical fixation of scrubber sludge and related materials is currently being offered by several commercial groups including the Dravo, IU Conversion Systems (IUCS), and Chemfix Corporations. At least two of the organizations cited offer processes which stabilize and solidify sludges via pozzolanic and other cementitious reactions between sludge/fly ash mixtures and small quantities of a lime-type additive. Laboratory data indicate that stabilized sludges have greatly improved mechanical properties, diminished rewatering tendencies, and substantially lower permeability and leachability compared to untreated materials.

Operating cost estimates for sludge fixation and disposal vary widely. Operating costs for utilities performing their own disposal are about $5.25-10.00 per wet ton for on-site disposal, exclusive of capital costs. Vendors' estimates are much lower, ranging from $2-6 per wet ton as a total disposal cost. IUCS and Chemfix estimates for complete costs, including capital investment and local transportation costs, are $4-5 per wet ton (50% solids). IUCS quotes a cost of $1.50-2.50 per wet ton for an on-site disposal operation;

this figure is exclusive of land acquisition costs. A Dravo spokesman gave a disposal cost for a situation involving pumping up to ten miles, exclusive of pond construction costs, of $1-3 per wet ton (35-40% solids). A specific case involving considerable land development and an 8-mile pumping distance is estimated to cost less than $5 per wet ton. Typical cases are expected to be in the range of $2.50-5.00/wet ton. The cost of $2.50/wet ton applied to Case 5 of Table 2 (limestone sludge including ash) results in an operating cost of about 0.6 mills/Kwh.

Due to the importance of sludge fixation processes and their potential for minimizing all potential environmental problems associated with sludge, it is considered essential to evaluate the following attributes of treated sludges as a function of time: leachability, permeability, mechanical strength, and rewatering tendencies. Also required are detailed capital and operating costs over a range of applications.

E. Other Disposal Methods

Other disposal options are available for sulfur oxide sludges, although they are not under investigation to nearly the same extent as ponding and landfill and may have water pollution potential. One of these is deep mine disposal whereby untreated or treated sludge is returned to the mines, possibly in "empty cars. However, the feasibility of this approach could be significantly influenced by transportation costs from power plant sites. Another sludge disposal method that has been proposed, deep well injection, involves disposal by deep well injection into permeable subterranean formations. EPA policy is to review this alternative on a case by case basis but considers deep well injection only as a last resort. No data are reported on this technique for sulfur oxide sludges; however, the high solids content of these materials

might cause rapid plugging of the subsurface strata, resulting in continually decreasing injection rates.

F. Current EPA R&D Programs

The most relevant government sponsored program relating to sulfur oxide sludges is the NERC-RTP program with The Aerospace Corporation (El Segundo, California) entitled "Study of Disposal of By-Products From Non-Regenerable Flue Gas Desulfurization Systems." This program, which will evaluate the technology of sludge disposal, was formalized during late 1972 and has the following major elements:

1. An inventory of sludge constituents in both the solid and liquid phases. Sludges produced from the following sorbent/fuel combinations are being studied: limestone/Eastern and Western coals, lime/Eastern coal, and double alkali/Eastern coal.

2. An evaluation of the potential water pollution and solid waste problems including consideration of existing or proposed water effluent, water quality, and solid waste standards or guidelines.

3. An evaluation of treatment/disposal techniques with emphasis on ponding and treated and untreated landfills. In particular, sludges treated by two or more commercially offered processes will be evaluated in the laboratory for mechanical properties, permeability, leachability, etc.

4. A recommendation of the best available technology for sludge treatment/disposal based on the elements delineated above.

The current Aerospace contract is limited to the sampling and analysis of sludges from only four power plant FGD systems. Because of the diversity of coal types and FGD systems, this was felt to be too small a data base upon which to draw the general conclusions needed to achieve the program objectives. In addition, results of the current program identified the need for (1) a more detailed examination of possible scrubber system alternatives for reducing the availability of soluble chemical species to the environment, (2) greater emphasis on the cost of sludge transport for disposal, and (3) a field study of disposal of both treated and untreated FGD system sludges. Therefore, a contract modification is currently being negotiated, the purpose of which is to accomplish the following:

1. Expand the sampling and analysis effort from four plants to eight, which will make the program results applicable to a broader range of power plant flue gas scrubbing applications.

2. Determine, through analytical and laboratory solubility studies, those chemical constituents which can be controlled by scrubber chemistry. Examine the possible effect of the results of the solubility studies on cost and technical adequacy of alternative sludge disposal methods.

3. Expand disposal cost analyses to include more detailed investigations of various transport modes; e.g., trucking, pumping, and barging.

4. Support an EPA field study of FGD sludge disposal at TVA's Shawnee Steam Plant, which will include test planning program coordination, analyses of liquid and solid samples, and reports.

In the EPA field study, sludges will be obtained from 10 Mw lime/limestone pilot scrubbers at the TVA Shawnee Power Station at Paducah, Kentucky, and will be placed into five nearby ponds. One pond will receive raw lime sludge; another will receive raw limestone sludge; the third will receive chemically conditioned lime sludge; and the last two will receive chemically conditioned (by two different processes) limestone sludge. Each pond will have a leachate well and a ground water well. Tests will be performed to determine the following: (1) the nature of the bottom soil of each pond; (2) the quality of the water from all wells; (3) the seepage through the bottoms of all ponds; (4) the interaction between the sludges and the bottom soil of each pond; and (5) the quality of the chemically conditioned sludges as to strength, permeability, and leaching effects.

NERC-Corvallis has initiated a contract with Aerospace Corporation directed toward determining the implications of open-loop or partially open-loop operation of lime/limestone FGD systems. Analyses of various sludge liquors will be performed and technologies for liquor treatment will be evaluated Resulting data will be used to ascertain the water pollution and reuse potential, for various plant uses, of treated and untreated scrubber liquors.

Two programs have recently been initiated at NERC-Cincinnati to evaluate the environmental effects of FGD sludge disposal. One of these is an interagency agreement with the U.S. Army Corps of Engineers' Waterways Experiment Station in Vicksburg, Mississippi. Under this agreement, the leachability and durability of raw and chemically fixed hazardous industrial wastes and FGD sludges are being studied. Five industrial sludges and up to six FGD sludges are being obtained for the

study. The FGD sludges obtained so far in the study include the following:

Eastern (high sulfur) coal - Lime
- Limestone
- Double Alkali

Western (low sulfur) coal - Limestone
- Double Alkali

The second program is also an interagency agreement, with the U.S. Army Materiel Command's Dugway Proving Ground, Dugway, Utah. Under this agreement research is being conducted to determine the extent to which heavy metals and other chemical constituents from 13 industrial and three FGD sludges could migrate through the soil in land disposal sites. After initial screening tests with a variety of U.S. soils, leachate column studies will be performed with two selected (best and worst) soils. Long-term permeability tests with selected clays are also planned for the FGD sludges.

NERC-Cincinnati is also currently considering a full-scale FGD sludge disposal demonstration program with an Eastern utility.

Additional information relevant to sludge disposal has been generated through NERC-Cincinnati efforts in mine drainage pollution control and solid waste disposal. EPA mine drainage activities have resulted in numerous reports dealing with sludge produced by neutralization of acid mine drainage. The reports cover areas such as in-situ sludge precipitation, sludge supernatant treatment, thickening and dewatering, use of latex as a soil sealant, and technical and economic feasibility of bulk transport.

Also, NERC-Cincinnati municipal sludge activities relate to the EPA sludge program under discussion. Examples include the following:

1. Methods of removing pollutants from leachate water.

2. Evaluation of landfill liners.

3. Development of mathematical models to determine effects of landfill leachate on groundwaters.

4. Leachate pollutant attenuation in soils.

5. Moisture movement in landfill cover material.

6. Forecasts of effects of air and water pollution controls on solid waste generation.

An attempt is being made to use the Aerospace program as the focal point for documenting all sulfur oxide sludge activities; close liaison is being performed by Aerospace with NERC-Corvallis, NERC-Cincinnati, sludge-producing utilities. and sludge treatment vendors.

III. ALTERNATIVE SULFUR BY-PRODUCTS

A number of sulfur containing by-products can be recovered from power plant flue gas desulfurization systems. These alternative sulfur by-products are sulfur, sulfuric acid, gypsum, sodium sulfate, ammonium sulfate, and liquid SO_2.

The production technologies for recovering SO_2 from such power plant flue gas desulfurization systems as sulfuric acid, sodium sulfate, ammonium sulfate, and gypsum have been commercially demonstrated in Japan. The production technology for recovering elemental sulfur has not yet been demonstrated on a power plant as an integral part of a FGD process although a successful demonstration of sulfur production has been completed on a smelter application. In 1975 EPA. Davy Powergas (formerly Wellman Lord) and Allied Chemical plan on demonstrating an integrated FGD system producing by-product sulfur at a plant of Northern Indiana Public Service Company (NIPSCO).

Table 6 compares FGD sulfur by-products in terms of potential quantities produced, market value, potential marketability, and disposal considerations.

The only alternative by-products that appear to have a significant potential market are sulfuric acid and sulfur. The overall problem of marketing sulfuric acid is quite complicated. The problems of marketing sulfur are intimately tied to the demand for sulfuric acid since 90 percent of the sulfur consumed in the United States is used in the production of sulfuric acid. There is probably a good chance that either the sulfur or the acid market could be penetrated to a moderate extent; this would mean that, in favorable sections such as the Midwest and Coastal Northeast, power plant abatement sulfur or sulfuric acid could be marketed. Due to marketing constraints, it is estimated that not more than 50,000 Mw equivalents of sulfur or sulfuric acid can be sold by 1980. This is comparable in magnitude to about 43 percent of the expected total FGD capacity in 1980 and about 50 percent of the current market for sulfuric acid.

Table 6. COMPARISON OF ECONOMIC, MARKETING, AND DISPOSAL ASPECTS OF FLUE GAS CLEANING BY-PRODUCTS[a]

By-Product	Annual Production From 1000 Mw Generating Plant With FGD[b] (metric tons/yr)	Current U.S. Consumption (metric tons/yr)	Current Market Price ($/metric ton)	Maximum FGD System Credit[c] (mills/Kwh)	Ability to Penetrate Market	Alternatives for Non-Marketable By-Product	Product Disposal-Related Advantages/Disadvantages As Compared to Untreated Scrubber Sludge
Sulfur	65,300	10,000,000	22-31	0.22	Fair (Up to about 5% of market will probably be penetrated. Fair chance of 10-30% of market either as S or H_2SO_4 since it is essentially the same market.)	Store/dispose (piles)	(1) Much less bulk (2) Less soluble (3) Dry (4) Potentially flammable (5) Potential H_2S odor problem (6) Potential erosion problem (7) Susceptible to chemical and biological oxidation
Sulfuric Acid	200,000	28,200,000	11-16	0.34	Good (Excellent chance of penetrating 75% of market. Good chance of penetrating 10-30% of market)	Store Neutralize & dispose as gypsum (piles, ponds, landfills)	Disposal product: gypsum (1) Less bulk (2) Easier to dewater
Gypsum	351,000	18,000,000	3-4	0.16	Questionable (Not demonstrated that wall board-grade gypsum can be made. All agricultural gypsum used in California. Portland Cement gypsum must be 1/4"-2" in size. By-product would have to be pelletized.)	Store/dispose (ponds, piles, landfills)	(1) Less bulk (2) Easier to dewater
Sodium Sulfate	290,000 (Produced by Wellman-Power Gas process as a purge equal to about 5-10% of the sulfur in the incoming flue gas)	1,450,000	16-27	0.72	Limited (Eastern market supplied by present by-product production. Western market equal to output from one 1000 Mw plant)	Store Neutralize & dispose as gypsum (ponds, piles, landfills)	Disposal product: gypsum (1) Less bulk (2) Easier to dewater

Table 6 (Continued). COMPARISON OF ECONOMIC, MARKETING, AND DISPOSAL ASPECTS OF FLUE GAS CLEANING BY-PRODUCTS[a]

By-Product	Annual Production From 1000 Mw Generating Plant with FGD[b] (metric tons/yr)	Current U.S. Consumption (metric tons/yr)	Current Market Price ($/ metric ton)	Maximum FGD System Credit[c] (mills/Kwh)	Ability to Penetrate Market	Alternatives for Non-marketable By-product	Product Disposal-Related Advantages/ Disadvantages As Compared to Untreated Scrubber Sludge
Ammonium Sulfate	270,000	2,400,000	27-35	1.14	Poor (66% of market presently supplied by by-product from chemical industry. Projected to increase to 100% by 1980.)	Store Neutralize & dispose as gypsum (ponds, piles, landfills)	Disposal product: gypsum (1) Less bulk (2) Easier to dewater
Liquid SO_2	130,000	86,740	N/A	N/A	Poor (Production from one 1000 Mw plant is greater than total U.S. market consumption)	Store Convert to S or gypsum and dispose	Disposal product: gypsum (1) Less bulk (2) Easier to dewater
Sludge	710,000 (784,000 short tons)	------	------	------	--------- Possible penetration of road bed & synthetic aggregate market.	Untreated disposal[d] (ponds)	
						Treated disposal (landfill)	(1) Improved physical properties (2) Less soluble (3) Reduced permeability & leachability

[a] For references, see Volume II, Table III-7.

[b] Assumptions: 6400 hr/yr operation, 3% S, 0.4 kg coal/Kwh, 85% SO_2 removal efficiency.

[c] Assuming 100% sale of product at lowest market price.

[d] There are potential ground and surface water pollution and land use/ reclamation problems with all disposal products shown. Untreated scrubber sludge may have high potential for these problems.

On the basis of by-product environmental considerations alone, the following order of preference is suggested:

1. Sulfuric acid or sulfur for sale, if a reliable market can be found - The preference between the two depends on the relative production, handling, and shipping costs which depend on local as well as technical factors. Generally, regenerable systems able to sell these products are economically competitive with lime/limestone FGD systems with disposal costs in the ranges of $4-10/wet ton of sludge (without ash) for lime scrubbing and $4-7/wet ton for limestone scrubbing.

2. Sulfur for storage - Sulfur production leads to substantially reduced quantities of the end-product with correspondingly less land usage. Although there may be some storage problems with sulfur, it should be relatively easily handled compared to sludge. It would also represent a potentially saleable commodity, when and if sulfur demand exceeds sulfur supply. Economics for sulfur storing systems would be competitive with lime/limestone systems with disposal costs greater than $7/wet ton of sludge (without ash) for limestone scrubbing and greater than $11/wet ton for lime scrubbing. Below these sludge disposal costs, the economics of sulfur storage systems would not be competitive with lime/limestone systems since they could assume no by-product credits and disposal of unmarketable sulfur would be an additional cost.

3. Gypsum for storage - Gypsum could be a favored end-product compared to sludge since it would dewater more readily thereby allowing easier and less expensive land reclamation.

4. Sludge disposal - The other by-products have a small potential market and are difficult to store without expensive conversion to gypsum or some other product. For this reason they are not anticipated to play a major role in FGD sulfur by-product disposal.